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A novel use of the caesium-137 technique to estimate human interference and historical water level in a Mediterranean Temporary Pond

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Abstract

The sustainability and the effects of human pressures on Omalos Mediterranean Temporary Pond (MTP), Chanea, Greece was assessed. The caesium-137 (^{137}Cs) technique was used in order to identify alleged unplanned anthropogenic interference (excavation) in the studied area. It was found that about one third of the ponds bed surface material had been removed and disposed of on the northeast edge, confirming unplanned excavations that took place in the MTP area some years ago. Nonetheless, five years after the excavation, the MTP's ecosystem (flora and fauna) had recovered, which reflect that these small ecosystems are resilient to direct human pressures, like excavations. Moreover with the ^{137}Cs technique it was possible to identify the historical water level of Omalos MTP, when the fallouts of the Chernobyl accident reached this area, in May of 1986. Therefore, the ^{137}Cs technique can be useful in the identification of the historical water level of small MTPs and other fragile ephemeral water bodies. Applications include the verification and validation of hydrological models.

Keywords: Caesium-137; soil erosion; Mediterranean Temporary Pond; historical water level; gamma ray spectrometry.

1. Introduction

Wetlands are being created and restored with great frequency around the world. The importance of wetland conservation is recognized worldwide, because they represent hot spots of biological richness as well as being a source of freshwater supply and food. Wetlands are very diverse in their nature, ranging from open water to forested ecosystems or from shallow permanent lakes to temporary ponds. In terms of conservation, some temporary standing freshwater wetlands are considered important habitats for conservation and are recognized by the Ramsar Convention on Wetlands. Furthermore, some are classified as priority habitats by the European Union Habitats Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (European Commission, 2007). Temporary ponds are shallow water bodies that remain flooded for a sufficiently long period of time during winter and spring to allow the development of (semi) aquatic vegetation and animal communities. They often occur in shallow depressions over impermeable ground and have a relatively small catchment area. The depression present a significant variability in size, shape and depth but are relatively small and shallow endorheic water bodies (i.e. closed, with no outflow), which are flooded, during the rainy season, for a sufficiently long period to allow the development of aquatic vegetation and hydromorphic soils, but are not in contact with permanently flooded habitats such as rivers. In this perspective, temporary ponds exhibit a self-regulating hydrology. The hydrological dynamics of these ponds and the consequent temporary availability of resources are crucial for these habitats' species specificity and diversity (Beja and Alcazar, 2003; Dimitriou et al, 2006; Zacharias et al, 2007; Canals et al, 2011; Pinto-Cruz et al, 2011).

There is not yet a widely accepted classification system for temporary ponds to characterize them with regard to specific environmental criteria. Temporary ponds are globally known under more than 30 different names; vernal pools, daya's, brumal pools, copular pools, ephemeral waters, etc. and in Greece with different names: arolithoi, rousies and kolympes. The use of numerous names indicates the lack of unique classification system for temporary ponds, which has possibly led to the deficiency of information about their main characteristics and the differences between the various types of these habitats. In the Mediterranean region there are many types of temporary ponds. They vary from small copular ponds (<1 m^2 < 50 cm deep, hollowed out in rocks) to almost permanent lakes, which sometimes cover an area of several hectares. In particular, Mediterranean temporary ponds (MTPs) are considered one of the most remarkable and most threatened freshwater European habitats. MTPs are poorly understood and highly endangered, suffering widespread degradation and loss due to increases in the area of land under intensive cultivation and urban use (Beja and Alcazar, 2003, Zacharias et al, 2007).

In Greece there are 18 temporary ponds sites, 73% of which are encountered in the Aegean islands due to the semi-arid climatic conditions that facilitate their existence (Figure 1). Only 1 of the 18 sites is located in the mainland, whereas the island of Crete has the highest presence of temporary ponds, compare to any other region in the country. The amount of rainfall in these islands rarely exceeds 600 mm a year and the prolonged dry period prevents permanent dominance of aquatic vegetation. Therefore, a primary determinant of species distributions and ecosystem processes is water availability, which is strongly affected by climatic conditions and human landscape use. To add, soil moisture and surface water level are key determinants of plant community composition and ecosystem function (Maclean et al., 2012). For these reasons, the knowledge of the historical water level of a MTP can infer a better understanding of its seasonal function and the phytoplankton assemblage; providing information about its sustainability. Moreover, this knowledge can be used as input for the verification, validation, and confirmation of mathematical and numerical models (Oreskes et al., 1994, Synolakis et al., 2008) that simulate long term water conditions and temporal scales of MTP and other temporary or permanent water ponds.

Figure 1: Spatial distribution of the Greek Temporary Ponds

Caesium-137 (^{137}Cs) is an artificial radionuclide that was inserted into the atmosphere mainly through the detonation of nuclear weapons and tests from the 1940s until the late 1970s and later on from the Chernobyl accident in 1986. When dust with the ^{137}Cs isotope settles on the ground, ^{137}Cs strongly bonds with soil particles, limiting its movement by chemical and biological processes (Ritchie & McHenry, 1990). From there on, any redistribution of ^{137}Cs, which can be measured via its strong gamma emission at 661.7 keV and is known as the ^{137}Cs technique, represents erosion and deposition paterns on the landscape (Kaste et al., 2006).

The ^{137}Cs technique has been successfully used for the ca. 30-50 years estimation of soil redistribution (erosion, accretion) by anthropogenic (e.g. tillage, urbanization activities etc) and natural (aeolian forces, precipitations) pressures (Chappell et al., 2011); while, recent papers from various countries continue to investigate the ^{137}Cs concentration in soil samples (Antovic et al., 2012; Daraoui, et al., 2012; Szabó et al., 2012). Moreover, a coordinated research project on assessing the effectiveness of soil conservation measures on erosion control has been organized by the International Atomic Energy Agency and its main conclusions have been recently published in a review paper (Dercon et al., 2012). Using a reference site, information about the evolution of adjacent areas can be extracted, since areas with higher ^{137}Cs yield are assumed to be areas of aggradation, and the areas with lower ^{137}Cs yield are assumed to have undergone topsoil erosion. Moreover, sediment accumulation rates can be estimated by comparing the vertical distribution of ^{137}Cs and locate sediment horizons (Ritchie & McHenry, 1990). In this work ^{137}Cs technique was used in order to identify the percentage of human disturbance (excavation) in Omalos MTP and for another novel use, which is the identification of the ponds' historical water level in May 1986, when Chernobil fallouts reached the area.

2. Methodology

2.1 Area of study and background of the problem

The Omalos plateau is located on Lefka Ori Mountains of Crete, Greece, at a mean altitude of 1.1 km above MSL, and is mainly used for agricultural activities. The mean annual rainfall is 1093.7 mm and the mean annual temperature is 9.3^{o}C (Ghosn et al., 2010). The geologic formations of the plateau are mainly metamorphic carbonate rocks belonging either to Trypali Unit or Plattenkalk Group, which are covered by Quaternary deposits. The Omalos plateau is the largest active polje of Western Crete and covers an area of approximately 6 km^2 (Alevras et al., 2007). It is an ecologically sensitive area, which is protected by a Natura 2000 network and it belongs to the Special Area of Conservation (SAC) named GR4340008 "LEFKA ORI KAI PARAKTIA ZONI". From 2002, it is part of "Samaria National Park". The plateau accommodates the natural MTP of Omalos (Figure 2), which is a priority habitat (Natura code: 3170*) in Annex I of the Directive 92/43/EEC. Due to its specific characteristics this pond has suffered significant human pressures and therefore may be prone to extinction.

Omalos MTP has a circular shape, with a maximum area of 8,000 m^2 and a maximum depth of 2.6 m, while the catchment area of the lake is approximately 10,000 m^2 (Stamati et al., 2008). Its bottom has mild slope and high accessibility and for this reason during the summer it is used as a livestock watering reservoir. In the winter, it concentrates runoff (rain and snow) and during the summer this water volume is slowly removed by evaporation and livestock watering needs, leading to high seasonal water level changes (Figure 2). The main environmental pressure is livestock breeding, since Stamati et al. (2008) estimated that there are 10,000 sheep and goats that graze in the area of the pond.

Figure 2: Seasonal fluctuation of the pond water level during (a) the winter (04/02/2003) and (b) the summer (23/08/2004) (Google Inc., 2012).

It has to be noted that human interference on MTPs should be avoided, since it can alter seasonal patterns, affect the richness of phytoplankton assemblages and threaten their sustainability (Naselli-Flores, & Barone, 2012). Nonetheless, all MTPs of Greece, except one, are affected by anthropogenic pressures such as, overgrazing, agriculture and hydrological disturbance that also comprise the most common threats to temporary ponds throughout Greece. The most common threat of the habitat originates from intensive agriculture which either expands over the temporary ponds or pollutes their water with fertilizers. In some cases, there is also artificial recharge of temporary ponds as a restoration practice, which often results in an extended wetting phase and can even make the ponds permanent (Dimitriou et al, 2006, Zacharias et al., 2007). The construction of cisterns in the region of Kourounes inside the area where the temporary pond of interest exist might be the reason why this area is not in the catalog of the protected areas of Greece.

The anthropogenic pressures on Omalos MTP did not stop on overgrazing and hydrological disturbance, but due to the high watering needs of livestock, an unplanned excavation took place in August 2006. According to eyewitnesses' reports, surface material was removed, by a small excavator, from the ponds center and was disposed of at the somewhere at the north edge, which at that time had lower topography compared to the other edges. Within hours, the local authorities stopped the works, as no permit had been issued, and such interference is prohibited in environmentally protected areas. The magnitude of the interference was not recorded at the time, and flora covered the biggest part of the works, while at the time of the field surveys, February and March 2011, only two fractions of the excavation trimline were still visible (Figure 3). The eyewitnesses' reports were contradictory and therefore the magnitude of the disturbance and the effects on its sustainability could not be assessed. Hence, the aim of this work is a thorough spatial analysis of the MTP area. For this purpose, the radioactive fallout ^{137}Cs technique was utilized, as to identify any anthropogenic activities, such as determining the excavated area and where this soil material was disposed. Moreover, the historical water level of the MTP was estimated based on a novel methodology.

2.2 Field measurements

2.2.1 Core Sampling

The first step was to establish reference sites (flat, undisturbed areas, and preferably covered by grass) and collect representative undisturbed ^{137}Cs core samples, in order to obtain the undisturbed depth profile of the area of interest (Schimmack and Schultz, 2006). Representative undisturbed ^{137}Cs samples were obtained from a nearby field and it was found that ^{137}Cs was mainly accumulated in the upper most soil layer (down to 6 cm), while its activity concentration had a total concetration of 82.3 Bq/kg and a mean concetration of 27.4 Bq/kg. Then, a sampling grid, with approximate dimensions of 80 by 100 m, was established inside Omalos MTP, and ^{137}Cs residuals of individual points on the grid were used (Kaste et al., 2006) in order to estimate soil acretion/erosion, deposition rates as well as identify the excavated area. In total four transects that formed a square inside the MTP of Omalos and run through the remaining fraction of the excavation trimline (Figure 3) were established. In each transect the core spacing was set to 5 m, while the spacing between the two visible excavation trimlines was higher and was set to 2.5 m.

In the beginning of the spring (during the last days of March and in the first days of April) 72 virtually undisturbed soil cores were acquired with the utilization of a 4cm diameter metallic hand corer soil sampler. The sampling was limited to surface sediment, and the depth ranged from 4 to 10 cm, depending on the soil moisture and coarse grain content. Each core was sectioned in 2 cm intervals, resulting in a total of 282 samples that were transferred to the laboratory for further processing.

2.2.2 Topographical analysis

A high resolution Digital Elevation Model (DEM) needed to be established in order to correlate the ^{137}Cs measurements with human activities and with the historical water level of the pond. For this reason, the core sample coordinates as well as the topography of the MTP were recorded with a Topcon Hyper-Pro real-time kinematic (RTK) global positioning system (Topcon Corp., Livermore, CA, USA), which has a static reading standard of ±15 mm vertical and ±10 mm horizontal. In addition, the fractions of the remaining excavation trimline as well as the water level at the time of the measurements were recorded (Tinkham et al., 2011). In total more than 2000 points were recorded and an accurate and high resolution Digital Elevation Model (DEM) of Omalos M.T.P. was created (Figure 3).

Figure 3: The DEM of the core samples and the remaining excavation trimline (yellow color) using Google earth's image (23/08/2004) as background.

2.3 Analytical measurements

The sectioned samples were dried, in order to remove the water content and passed through a 2 mm sieve in order to remove the coarser grain content. To estimate the activity concentration (Bq/kg) of ^{137}Cs, a high purity germanium detector, of 70% relative efficiency, placed into a lead shielding of 10cm thickness, was utilized. The samples were placed into standard polyethylene containers and measured by means of low background gamma ray spectrometry. The calibration of the detector was performed using the NIST 4357 SRM standard and the uncertainties were given at the

95% confidence level. The activity concentrations (Bq/kg) of ^{137}Cs and ^{40}K were estimated in this study, but since no correlation between them was found only the ^{137}Cs will be presented. The results are decay-corrected to January first 2011.

2.4 3D visualization

The activity concentration of each sample and the data from the topographic survey were analyzed in a 3D visualization software (RockWorks15) and planar and vertical images as well as 3D block models were created. These visualizations can improve the understanding of the spatial horizontal and vertical distribution of ^{137}Cs.

3. Results and Discussion

3.1 Anthropogenic disturbance

The 282 samples, representing the 72 cores from the four transects, were assessed in terms of their vertical and spatial ^{137}Cs distribution. It has to be noted that when referring to small scale areas (<10 m), like in the Omalos M.T.P., the ^{137}Cs soil concentrations and amounts typically vary by 10% to 30%, which most likely represents the spatial heterogeneity of the depositional processes (Kaste et al., 2006). This variation is relative small and therefore does not affect the accuracy of the method.

It was observed that ^{137}Cs is mainly accumulated in the upper most soil layer (down to 6 cm), while the total activity concentrations of the core samples varied from zero to 231 Bq/kg. For the undisturbed area the siltation rate in the pond reached a maximum of 0.7 mm/year, for the past 28 years, but siltation rates for the pond's center were unavailable, since the ponds bed had already been disturbed. Based on their ^{137}Cs concentration, the samples were separated into three different groups

(Table 1). The first group (cores A5D-A9D, B3-B4, C6-C7, B9, D10-11) contained very low to zero concentrations, the second group (C1, B18-B19) had a relative stable vertical ^{137}Cs concentration throughout the core depth, and the third group had the expected distribution that represent undisturbed soil (Kaste et al., 2006).

Table 1. Mean ^{137}Cs valuse for the first 3 sections of each core.The values are in Bq/kg and decay corrected to 01/01/2011.

The hypothesis that the cores containing very low to zero ^{137}Cs concentrations represent the excavated area was supported by the remaining fractions of excavation trimline, as shown in Figure 4. Specifically, only two fractions of the excavation trimline were visible (dash lines shown in Figure 4) and the core samples that were in their inner part (cores A7 to A9D, D10 and D11) did not contain any ^{137}Cs. The cores that were on the edges of the excavation trimlines contained very low concentrations, which can be attributed to the fact that soil material from the upper edge of the trimline, that contained ^{137}Cs, was eroded and distributed along the width of the trimline. Finally, on the northeast part of the pond high and relatively stable ^{137}Cs concentrations (B18 and B19, C1 and C3) are observed throughout the depth of the cores. In light of the facts that (a) the excavation activities dealt mainly with surface sediments, which had a relative stable spatial horizontal distribution, and that (b) according to eyewitnesses testimonies, this soil material was disposed somewhere at the north edge, it can be deducted that the disposal areas of the excavated material will have a stable ^{137}Cs distribution. This was evident during the analytical measurements, where it is shown that the vertical ^{137}Cs distribution of the northeastern area is high and relatively stable; indicating that this was the disposal area during the excavation works (Figure 4). The rest of the cores were not affected by the excavation and show the actual ^{137}Cs distribution in the undisturbed soil material. Therefore, estimation of the ^{137}Cs concentration can become a useful tool to accurately identify disturbed soil as time passes by.

Figure 4. Spatial distribution of the total ^{137}Cs of each core. The excavated areas are represented with pinkish color and the area were these material was disposed of is represented by red color (northeast edge). Green colors represent the area that was below the May 1986 water level and the blue ones the unaffected area that was above the May 1986 water level.

Finally, it was found that the unplanned excavation caused detrimental effects on the MTP local environment, since almost one third of the bottom surface sediment was removed and improperly disposed at its northeastern edge (i.e. cores B18 and B19, C1 and C3). Nevertheless, about four years later Ghosn et al. (2010) examined the MTP and found it to have the expected plant assemblage, which was the distinct circular zonation that reflects the gradient of water level and period of submergence. Moreover, the distribution of life forms in the Omalos MTP was also similar to those observed in other MTPs, with therophytes being the dominant life form (Ghosn et al., 2010).Therefore, it is concluded that Omalos M.T.P. ecosystem was resilient to the unplanned excavation.

3.2 Historical water level

The major invasion of ^{137}Cs in the Greek territory took place after the Chernobyl disaster at 1986 on the 26th of April. Hence, this fact can become a major advantage for discovering evidence that can be further used and constitute a record of scientific data. A novel methodology to draw up the historical water level of ephemeral water bodies based on the estimation of ^{137}Cs concentration will be demonstrated further down.

The analysis of the results of Table1 revealed a pattern in the undisturbed soil and this was the fact that the core samples that were collected from the unaffected greater central area of the pond yielded a significantly higher concentration of ^{137}Cs when compared with the samples that were closer to the edges of the pond. For example, in Figure 5 it is shown that for sample D1 (i.e. found near the edge of the MTP) the maximum ^{137}Cs concentration was 22.56 Bq/kg at about 2-4 cm deep and total a 56.3 Bq/kg, while sample D4 (i.e. near the centre of the MTP) presented about a five times higher maximum concentration (98.02 Bq/kg) at 0-2 cm depth and 4 times higher total concentration (220.3 Bq/kg). Ritchie and McHenry (1990) found that about 93% of the ^{137}Cs that is found on grass is washed off during the first year by natural causes, such as rain, snow. Moreover, another important factor is that the grass that was above the water level of the pond was grazed at the time by local livestock and other animals, while the ^{137}Cs that ended up in the pond was free to settle and bond with the ground. Therefore a plausible scenario could be the fact that the ^{137}Cs fallouts that settled on the grass around the pond, were later washed off (excluding the amounts that were eaten by livestock at that time), to end up in the pond's aquatic body, where ^{137}Cs was diffused and settled uniformly onto the bottom of the pond. Then, during the summertime of the same year, the M.T.P. was partially or completely dried, and the ^{137}Cs was stabilized and bound to the soil. To confirm this hypothesis, the spatial distributions of the highly ^{137}Cs concentrated samples were correlated with the topography of the pond that was acquired by the real-time kinematic (RTK) global positioning system and these results are shown at Figure 5. Figure 5d shows that all cores from transect D had an altitude lower than 1059.6 ± 0.1 m thus indicating that this represents the trimline of the historical water level of the M.T.P. of April 1986. Furthermore, the same trend stands for the other transects A, B and C and can be seen at Figures 5a, 5b and 5c, respectively. However, at these transects the historical water level limits are not so clear since these are the more disturbed parts of the pond from anthropogenic activities (non-planned excavation works after 1986).

Figure 5. The horizontal and vertical ^{137}Cs distribution of (a) transect A, (b) transect B, (c) transect C, and (d) transect D. Y axis is exacerbated with the vertical distance between two consecutive lines to be 1 m, while in X axis the distance between each core is 10 m. The ^{137}Cs depth distribution (every 2 cm) is presented by the red strips, with higher length to correspond to higher ^{137}Cs intensity.

Thus, the ^{137}Cs technique can be also used in order to estimate the historical water level of ephemeral water bodies and therefore provide measurements that can be utilized in a variety of studies, including the validation and verification of hydrological models.

4. Conclusion

The radioactive fallout ^{137}Cs technique was successfully utilized to identify anthropogenic activities that interfered with the fragile ecosystem of an ephemeral water body in Greece. The results showed that excavated works that occurred in the Mediterranean Temporary Ponds (MTP) area could be identified as well as the place where the excavated soil material was disposed. For the case of Omalos MTP, it was found that about one third of its bottom surface was removed and disposed of along its NE edge but the local ecosystem was resilient enough and was able to recover within a matter of years.

Moreover, the method was used to estimate the historical water level of the MTP releasing significant scientific data that can be further used by other researchers specializing in other scientific fields, such as hydrology.

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List of Tables

Table 1

Core	^{137}Cs	Core	^{137}Cs	Core	^{137}Cs	Core	^{137}Cs
A1	19.85	A17	36.91	B12	52.14	C12	4.94
A2	20.38	A18	37.82	B13	18.20	C13	31.62
A3	20.83	A19	33.49	B14	25.49	C14	30.24
A4	24.40	A20	28.74	B15	15.92	C15	25.59
A4D	35.63	A21	20.94	B16	17.71	C16	27.34
A5	63.53	A22	17.98	B17	42.98	C17	43.61
A5D	53.44	-	-	B18	29.91	-	-
A6	8.226	B1	20.07	B19	29.84	D1	16.52
A7	0	B2	26.77			D2	37.82
A8	0	B3	17.50	C1	75.39	D3	45.97
A9	0	B4	4.20	C2	29.91	D4	67.00
A9D	0	B5	28.04	C3	40.89	D5	39.75
A10	60.81	B6	63.53	C4	34.24	D6	70.61
A11	59.52	B6D	73.42	C5	21.01	D7	70.37
A11D	40.43	B7	50.87	C6	11.27	D8	37.84
A12	27.05	B7D	52.05	C7	7.37	D9	64.04
A13	44.39	B8	32.85	C8	28.25	D10	0
A14	26.22	B9	7.32	C9	29.56	D11	0
A15	53.93	B10	41.33	C10	22.44	D12	30.50
A16	32.67	B11	15.71	C11	57.37	D13	27.33

Figure Captions

Figure 1: Spatial distribution of the Greek Temporary Ponds.

Figure 2: Seasonal fluctuation of the pond water level during (a) the winter (04/02/2003) and (b) the summer (23/08/2004) (Google Inc., 2012).

Figure 3: The DEM of the core samples and the remaining excavation trimline (yellow color) using Google earth's image (23/08/2004) as background.

Figure 4. Spatial distribution of the total ^{137}Cs of each core. The excavated areas are represented with pinkish color and the area were these material was disposed of is represented by red color (northeast edge). Green colors represent the area that was below the May 1986 water level and the blue ones the unaffected area that was above the May 1986 water level.

Figure 5. The horizontal and vertical ^{137}Cs distribution of (a) transect A, (b) transect B, (c) transect C, and (d) transect D. Y axis is exacerbated with the vertical distance between two consecutive lines to be 1 m, while in X axis the distance between each core is 10 m. The ^{137}Cs depth distribution (every 2 cm) is presented by the red strips, with higher length to correspond to higher ^{137}Cs intensity.

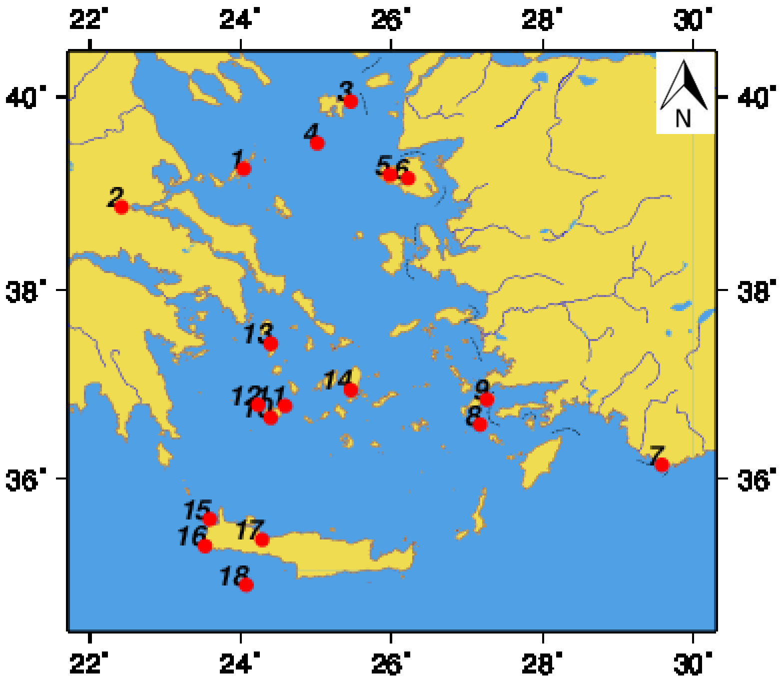


Figure 1


a
b
Image © 2012 DigitalGlobe
Google earth
Image © 2012 DigitalGlobe
Google earth

Figure 2

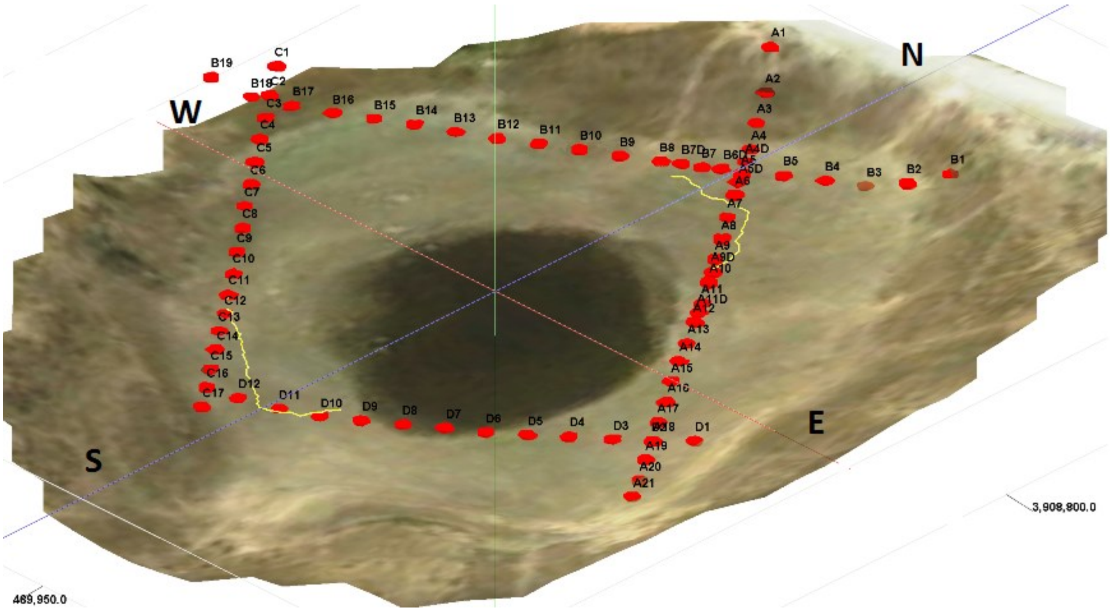
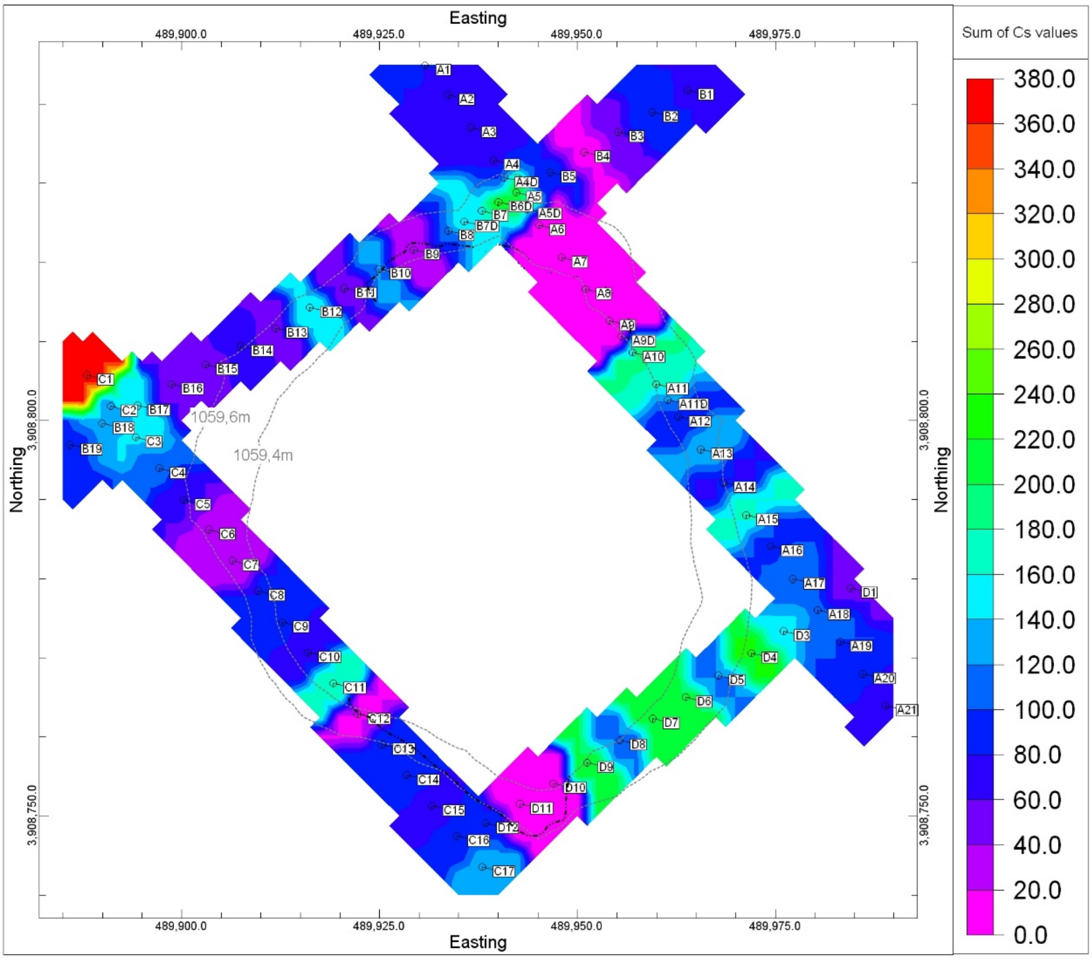


Figure 3


Easting
489,900.0
489,925.0
489,950.0
489,975.0
Northing
3,908,800.0
3,908,750.0
Sum of Cs values
380.0
360.0
340.0
320.0
300.0
280.0
260.0
240.0
220.0
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1059,6m
1059,4m
Figure 4

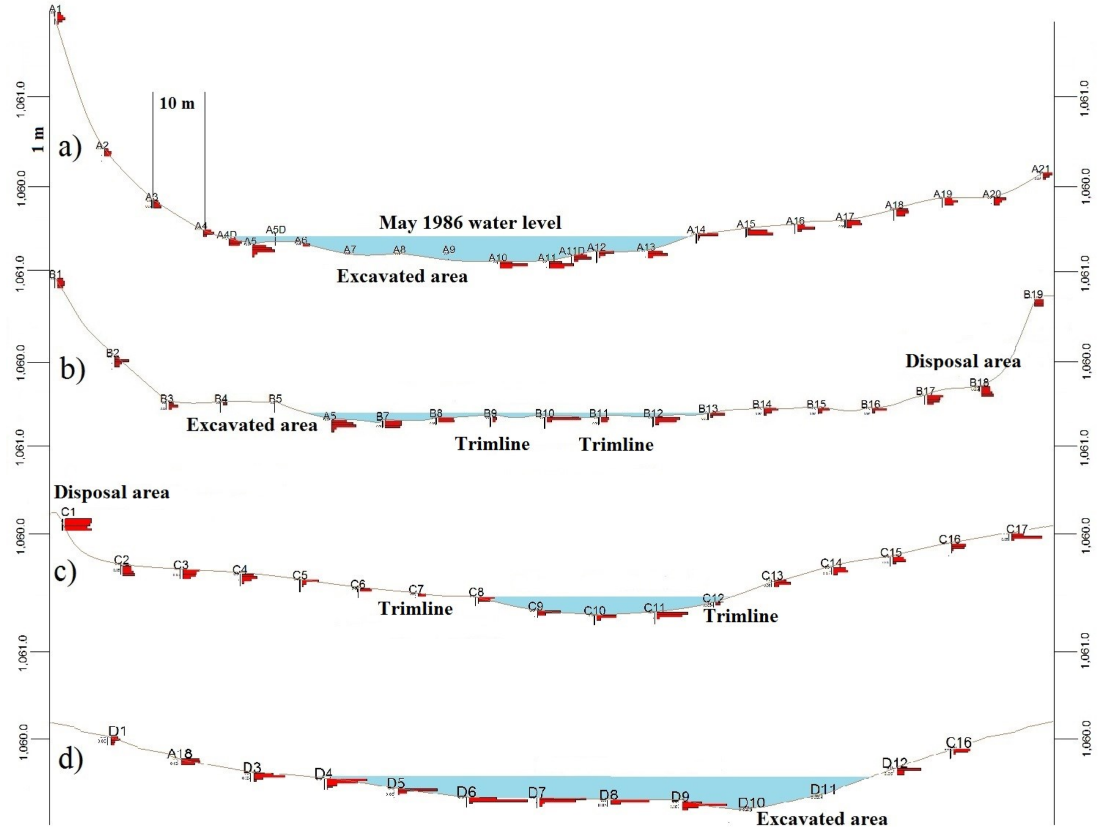

10 m
1 m
a)
May 1986 water level
Excavated area
b)
Disposal area
Excavated area
Trimline
Trimline
Disposal area
c)
Trimline
Trimline
d)
Excavated area

Figure 5.